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Spectral Identification of New Galactic cLBV and WR Stars

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Abstract. We have undertaken a near-IR spectral survey of stars associated with compact nebulae recently revealed by the *Spitzer* and WISE imaging surveys. These circumstellar nebulae, produced by massive evolved stars, display a variety of symmetries and shapes and are often only evident at mid-IR wavelengths. Stars associated with ~50 of these nebulae have been observed. We also obtained recent spectra of previously confirmed (known) luminous blue variables (LBVs) and candidate LBVs (cLBVs). The spectral similarity of the stars observed when compared directly to known LBVs and Wolf-Rayet (WR) stars indicate many are newly identified cLBVs, with a few being newly discovered WR stars, mostly of WN8-9h spectral type. These results suggest that a large population of previously unidentified cLBVs and related transitional stars reside in the Galaxy and confirm that circumstellar nebulae are inherent to most (c)LBVs.

Nebulae as signposts to the most massive stars

The *Spitzer* MIPSGAL (Carey et al. 2009) and GLIMPSE (Benjamin et al. 2003) surveys, and to a lesser degree other *Spitzer* Legacy Programs, have led to a new discovery path for the most massive stars in our Galaxy by the signpost their 24 and 8 μm bright nebulae signal in the images. These impressive nebulae indicate that massive star progenitors reside within, and hence where to search for them. Optical compact circumstellar nebulae associated with LBVs and WR stars have been known for decades (e.g., Nota et al. 1995; Dopita et al. 1994). The discovery potential in the IR was demonstrated by a few examples found in the *MSX* mid-IR survey data (e.g., Egan et al. 2002; Clark et al. 2003). The application of this technique has exploded recently with huge number of such nebulae having been identified through exploration of the extensive archival *Spitzer* database (e.g., Gvaramadze, Kniazev & Fabrika 2010a; Wachter et al. 2010; Mizuno et al. 2010). The hunt for the progenitor stars that produce these nebulae requires spectroscopy to identify the stars and their evolutionary state, primarily in the IR as the stars are typically undetected in the optical. There are often at least several potential stellar candidates. Figure 1 illustrates the case for MN 96 (#54 in Wachter et al. 2010). The left panel displays the 24 μm shell, with a bright source marked to the left of center. Following this source to shorter wavelengths to the right the 8 μm, 2MASS K_s,

and our deep I-band imaging all detect the source. The POSS II IR and red plates do not clearly detect the source, whereas we have optically recovered it. We are carrying out a spectral survey of stars associated with the newly discovered nebulae in order to identify and classify them. Highlights of our results are presented here.

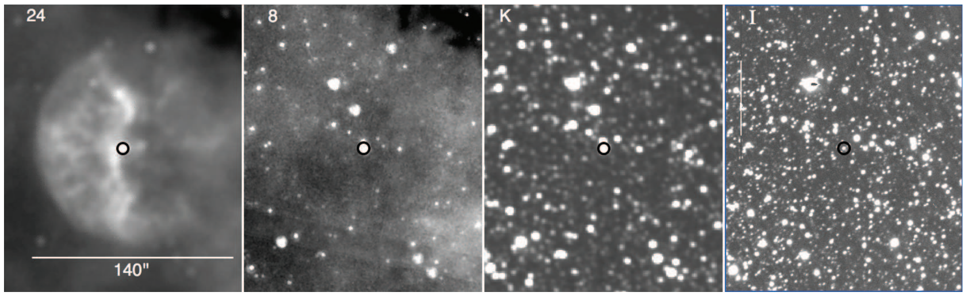

Figure 1. *Left to right*: 24 μm MIPS nebula MN 96 (Gvaramadze et al. 2010a) with the off-center progenitor star marked, followed by IRAC 8 μm, 2MASS K_s, and our deep FTS I-band image. The spectrum of the marked star is discussed in Stringfellow et al. (2012) and Wachter et al. (2011).

Spectroscopic identification of the progenitor stars

A near-IR spectral survey of the stars identified within the nebulae, as outlined above, has been conducted (Stringfellow et al. 2012, and in preparation). Primary facilities utilized include the APO, ESO-VLT, NASA-IRTF, and Palomar-Hale telescopes. IR spectra have been obtained for stars associated with ~50 shells, and many appear to be cLBVs, displaying strong emission lines of H, He I, Mg II, Na I, and often, but not always, Fe II. Occasionally, [Fe II] emission lines are present. Figure 2 presents a selection of 6 newly identified cLBVs, along with new spectra of previously known LBVs and cLBVs for comparison. All spectra shown in Figure 2 display Fe II 2.089 μm emission with varying strength. Most LBVs are believed to undergo S Dor cycles, where their atmospheres expand and contract, resulting in cool temperatures with large radii at peak light, and hotter temperatures at minimum radii and brightness (e.g., Stahl et al. 2001, for the LBV AG Car). If all these stars are undergoing active S Dor cycles, they would correspond to brighter phases when they are at larger radii where Fe II forms at cooler temperatures in the cycle; monitoring of these stars continues.

Stringfellow et al. (2012) present a few examples of cLBVs from our survey that are void of Fe II emission in their K-band spectra, including MN 96, MN 112, and MN 76. The near-IR spectra of these stars are classified as Fe II deficient cLBVs, perhaps indicating they are currently in a hot S Dor phase, and/or transitioning to a late-WN phase. While Fe II 2.089 μm emission is weak in P Cygni compared to many other (c)LBVs, and relative to its own emission lines in the K-band (see Figure 2), Fe II is entirely absent in the K-band spectra presented in Stringfellow et al. (2012), including MN 112. However, MN 112 is virtually identical to P Cygni over the optical spectral range shown by Gvaramadze et al. (2010b), which contains numerous Fe III lines but no Fe II lines, indicating a hotter line forming region. The star associated with MN 80 was previously classified as G7 I (Wachter et al. 2010), which is clearly disparate with the spectrum shown in Figure 2. There are two possible reasons for this: either a different star was observed by Wachter et al. (2010), or the spectrum has changed dra-

matically between the two observations. The complete survey has identified dozens of new cLBVs, considerably increasing the known Galactic population of such stars, and additional WR stars (see also Stringfellow et al. 2012, and in preparation).

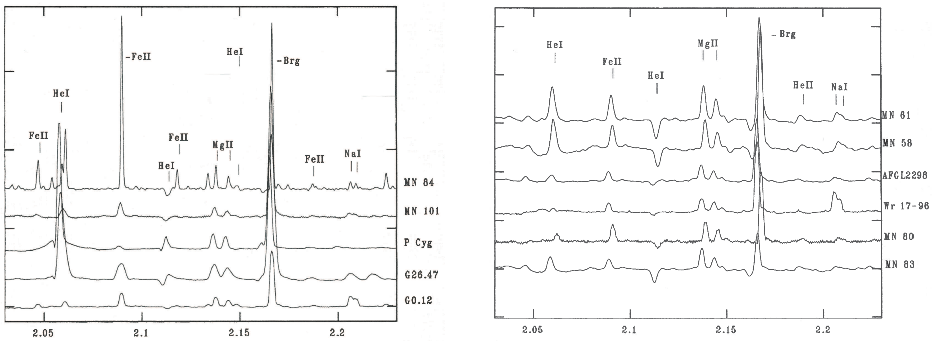

Figure 2. Normalized *K*-band spectra of the central stars associated with 6 new MIPS nebulae (Gvaramadze et al. 2010a). New spectra of previously known LBVs P Cyg, AFGL 2298, G0.120−0.048 (Mauerhan et al. 2010), and cLBVs Gal 026.47+00.02 and Wray 17-96 are also shown.

Discovery space of mid-IR shells remains vast

The MIPS nebulae catalogues on which our spectroscopic study is based remain incomplete. We have discovered further nebulae (e.g., Gvaramadze et al. 2011) using the WISE all-sky survey (Wright et al. 2010). Optical follow-up spectroscopy of two central stars with SALT indicate their spectra are very similar to those of the prototype LBV P Cygni, which implies the LBV classification for these stars as well (Gvaramadze et al., in preparation). Our study continues with further discoveries anticipated.

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References

Benjamin, R.A., et al., 2003, PASP, 115, 953
Carey, S.J., et al., 2009, PASP, 121, 76
Clark, J.S., et al., 2003, A&A, 412, 185
Dopita, M.A., et al., 1994, ApJS, 93, 455
Egan, M.P., et al., 2002, ApJS, 572, 288
Gvaramadze, V.V., Kniazev, A.Y., Fabrika, S., 2010a, MNRAS, 405, 1047
Gvaramadze, V.V., et al., 2010b, MNRAS, 405, 520
Gvaramadze, V.V., et al., 2011, A&A, in press (astro-ph/1109.2116)
Mauerhan, J.C., et al. 2010, ApJ, 713, L33
Mizuno, D.R., et al., 2010, AJ, 139, 1542
Nota, A., Livio, M., Clampin, M., Schulte-Ladbeck, R., 1995, ApJ, 448, 788
Stahl, O., et al., 2001, A&A, 375, 54
Stringfellow, G.S., et al., 2012, in IAU Symp. 282 *From Interacting Binaries to Exoplanets: Essential Modeling Tools*, eds. M. Richards & I. Hubený, in press
Wachter, S., et al., 2010, AJ, 139, 2330
Wachter, S., et al., 2011, BSRSL, 80, 322
Wright, E.L., et al., 2010, AJ, 140, 1868